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(54) **ADDITIVE MANUFACTURING OF METAL MATRIX COMPOSITE FEEDSTOCK**

ADDITIVE FERTIGUNG VON METALLMATRIX-VERBUNDWERKSTOFFROHMATERIAL

FABRICATION ADDITIVE DE CHARGE D'ALIMENTATION DE COMPOSITE À MATRICE MÉTALLIQUE

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## Description

## BACKGROUND

**[0001]** The present invention relates generally to additive manufacturing, and more particularly to a feedstock therefor that includes a pre-ceramic polymer.

**[0002]** Laser Powder Bed Fusion (LPBF) is an additive manufacturing process involving the construction of a three-dimensional article by selectively projecting a laser beam having the desired energy onto a layer of feedstock particles. When coupled with computer aided design apparatus, LPBF is an effective technique for producing prototype as well as production articles. Other such additive manufacturing processes utilize an electron beam within a vacuum. Various nanoparticles have heretofore been included in feedstock, but proper mixing and distribution of the particles in a bulk feedstock have been difficult to achieve. Jakubenas et al., in "Silicon Carbide from Laser Pyrolysis of Polycarbosilane", Journal of the American Chemical Society, vol. 78, no. 8, 1995, US 2002/035026 A1 and Zocca et al., in "SiOC ceramics with ordered porosity by 3D-printing of preceramic polymer" Journal of Material Research, vol. 28, no. 17, 2013, disclose prior art arrangements relating to additive manufacturing.

## SUMMARY

**[0003]** A feedstock powder for an additive manufacturing process, according to one aspect of the present invention, is claimed in claim 1. A method of additive manufacturing, according to another aspect of the present invention, is claimed in claim 4. Various embodiments of the invention are set forth in the dependent claims.

**[0004]** These features and elements as well as the operation thereof will become more apparent in light of the following description and the accompanying drawings. It should be understood, however, the following description and drawings are intended to be exemplary in nature and non-limiting.

## BRIEF DESCRIPTION OF THE DRAWINGS

**[0005]** Various features will become apparent to those skilled in the art from the following detailed description of the disclosed non-limiting embodiment(s). The components in the drawings are not necessarily to scale. Moreover, in the drawings, like reference numerals designate corresponding parts throughout the several views. The drawings that accompany the detailed description can be briefly described as follows:

FIG. 1 is a schematic view of one example additive manufacturing system;

FIG. 2 is a schematic cross-section of a feedstock for an additively manufactured article of manufacture not according to the invention; and

FIG. 3 is a schematic cross-section of a feedstock for an additively manufactured article of manufacture according to the invention.

## DETAILED DESCRIPTION

**[0006]** FIG. 1 schematically illustrates an additive manufacturing system 20. Example additive manufacturing systems 20 include, but are not limited to, Stereolithography (SLA), Direct Selective Laser Sintering (DSLS), Electron Beam Sintering (EBS), Electron Beam Melting (EBM), Laser Engineered Net Shaping (LENS), Laser Net Shape Manufacturing (LNSM), Direct Metal Deposition (DMD), Direct Metal Laser Sintering (DMLS) and others.

**[0007]** The system 20 generally includes a build platform 22, a laser 24, a rigid recoater blade system 26, a scanner head 28, a dispenser platform 30, a build chamber 32 and a control 34. It should be appreciated that various components and subsystems may additionally or alternatively provided. The additive manufacturing process essentially "grows" articles from three-dimensional information, for example, a three-dimensional computer aided design (CAD) model. The three-dimensional information is converted into a plurality of slices, where each slice defines a cross section of the article for a predetermined height of the slice. The additive manufactured component is then "grown" slice by slice, or layer by layer, until finished.

**[0008]** The build platform 22 and the dispenser platform 30 are contained within the build chamber 32 that is closed hermetically to receive an inert gas to avoid unwanted reactions of a melt pool formed from a feedstock 36. The build chamber 32 also includes a window through which the laser beam from the laser 24 may pass to selectively melt the feed stock 36. An example laser 24 includes a $CO_2$ laser that can operate in a continuous mode at a wavelength of approximately 10590 nm, which is infrared. However, other melt systems such as electron beam will also benefit herefrom. The laser 24 is selectively controlled via the control 34 and in accordance with a CAD file containing detailed dimensions of the desired article and its associated cross-sections.

**[0009]** In general, operation according to one disclosed non-limiting embodiment distributes the feedstock 36 to the build platform 22 from the dispenser platform 30 by the recoater blade 26 in response to the control 34. The build-up or "growth" of the article of manufacture W is directed in a layer-by-layer manner within the feedstock 36. That is, a computer file of the article of manufacture W is sliced into discrete layers having a certain thickness, which cumulatively form the three-dimensional configuration of the article of manufacture W. Each layer includes an essentially two-dimensional cross-sectional contour of the article of manufacture W.

**[0010]** The feedstock 36 is formed of a pre-ceramic polymer 40 and a base material 42.

**[0011]** The pre-ceramic polymer 40 includes silicon carbide or silicon nitride, that are temperature tailored to the desired temperature tailored base material 42. That is, the pre-ceramic polymer 40 is selected to pyrolize at a temperature conducive to the melt pool temperature of the base material 42. For example, a pre-ceramic polymer 40 that pyrolizes at a relatively higher temperature may be utilized with base material 42 that melts at a higher temperature such as nickel while a pre-ceramic polymer 40 that pyrolizes at a relatively lower temperature may be utilized with base material 42 that melts at a relatively lower temperature such as aluminum. It should be appreciated that the polymer may be added into a molten metal, such that the heat of the melt pyrolyzes the polymer into a ceramic phase, then the metal freezes with that secondary phase incorporated. The polymer may alternatively or additionally be reacted through outside heating such as a furnace, laser, electron beam, arc heat source, plasma heat source or other heat source. The pyrolyzed polymer that results may then be crushed or otherwise converted into a powder that can then be milled, spray dried, granulated, or otherwise combined with the metal to provide the feedstock 36. The feedstock 36 may include the preceramic polymer 40 at a volumetric ratio of about 1% to 50% and preferably about 1% to 10%.

**[0012]** The feedstock 36 is primarily described herein as a granulated powder typically utilized as a powder bed process or a laser applied powder process. In addition, the base material 42 includes nickel.

**[0013]** In one feedstock not according to the invention, the pre-ceramic polymer 40 coats the base material 42 and defines a particle size in the range of 5 to 200 microns (see FIG. 2). The pre-ceramic polymer 40 may coat the base material 42 via spray drying, coating, or other applicable method. Additionally, wire or strip could be coated or cored to have the same effect on wire additive processes such as laser applied or electron beam applied wire processes.

**[0014]** In another disclosed non-limiting embodiment, the pre-ceramic polymer 40 forms an agglomerate with the base material 42 of about 10-200 microns (see FIG. 3). The powder (e.g., agglomerate) includes a binder, and the binder is poly vinyl alcohol. It should also be appreciated that the pre-ceramic polymer 40 may be blended with the base material 42 for applicability in graded articles of manufacture W.

**[0015]** The rigid recoater blade system 26 is driven to sweep and spread a portion of the feedstock 36 on the build platform 22 from the raised dispenser platform 30. Corresponding to the first cross-sectional region of the article of manufacture W, the control 34 controls the laser beam to selectively scan the deposited feedstock 36 within the confines of the defined boundaries of that layer. The laser beam heats the powder so as to form a melt pool typically about 0.5 - 1 mm in size such that the feedstock 36 is joined together for that layer.

**[0016]** After the laser 24 has processed each layer, the recoater blade 26 again distributes fresh feedstock 36 onto the build platform 22 from the raised dispenser platform 30 and over the partially grown article of manufacture W, which is lowered so as to correspond to the layer thickness that is to be next applied. That is, the rigid recoater blade system 26 can move back and forth to deliver the feedstock 36 from the dispenser platform 30 to the build platform 22 and level the powder surface of the feedstock 36.

**[0017]** The feedstock 36 of pre-ceramic polymer 40 and the base material 42 is utilized within the additive manufacturing process such that as the feedstock 36 is incorporated in the melt pool, and/or reacts with the melt pool, such that the feedstock 36 forms desirable secondary phases and the pre-ceramic polymer is pyrolized to form well dispersed fine precipitates in the microstructure of the base material 42. These precipitates do not pile up as has been a problem when adding nano-particles directly to a melt pool but may not be evenly dispersed throughout the metal matrix composite (MMC) article of manufacture W. Nonetheless, the MMC article of manufacture W with pyrolized pre-ceramic polymer 40 has been found to lead to advantageous graded properties. That is, selective incorporation of feedstock 36 of preceramic polymer 40 and the base material 42 facilities the ability to grade properties within an added manufacture article of manufacture to produce exceptional properties.

**[0018]** The use of the terms "a" and "an" and "the" and similar references in the context of description (especially in the context of the following claims) are to be construed to cover both the singular and the plural, unless otherwise indicated herein or specifically contradicted by context. The modifier "about" used in connection with a quantity is inclusive of the stated value and has the meaning dictated by the context (e.g., it includes the degree of error associated with measurement of the particular quantity). All ranges disclosed herein are inclusive of the endpoints, and the endpoints are independently combinable with each other. It should be appreciated that relative positional terms such as "forward," "aft," "upper," "lower," "above," "below," and the like are with reference to the normal operational attitude of the vehicle and should not be considered otherwise limiting.

**[0019]** Although the different non-limiting embodiments have specific illustrated components, the embodiments of this invention are not limited to those particular combinations. It is possible to use some of the components or features from any of the non-limiting embodiments in combination with features or components from any of the other non-limiting embodiments.

**[0020]** It should be appreciated that like reference numerals identify corresponding or similar elements throughout the several drawings. It should also be appreciated that although a particular component arrangement is disclosed in the illustrated embodiment, other arrangements will benefit herefrom.

**[0021]** Although particular step sequences are shown, described, and claimed, it should be understood that steps may be performed in any order, separated or combined unless otherwise indicated and will still benefit from the present disclosure.

**[0022]** The foregoing description is exemplary rather than defined by the features within. Various non-limiting embodiments are disclosed herein, however, one of ordinary skill in the art would recognize that various modifications and variations in light of the above teachings will fall within the scope of the appended claims. It is therefore to be appreciated that within the scope of the appended claims, the disclosure may be practiced other than as specifically described. For that reason the appended claims should be studied to determine true scope and content.

## Claims

**1.** A feedstock powder (36) for an additive manufacturing process, comprising:

a pre-ceramic polymer (40) intermixed with a base material (42), wherein the base material (42) is metal and an agglomerate with the pre-ceramic polymer (40); and
a binder intermixed with the base material (42) and the pre-ceramic polymer (40), wherein the binder is poly vinyl alcohol,
wherein the pre-ceramic polymer (40) is pyrolizable into silicon carbide or silicon nitride and the base material (42) includes nickel.

**2.** The feedstock as recited in claim 1, wherein the pyrolyzed pre-ceramic polymer (40) forms a volumetric ratio of about 1% to 50%.

**3.** The feedstock as recited in claim 2, wherein the pyrolyzed pre-ceramic polymer (40) forms a volumetric ratio of about 1% to 10%.

**4.** A method of additive manufacturing comprising: melting and pyrolizing a feedstock powder (36) as claimed in claim 1, 2 or 3 .

**5.** The method as recited in claim 4, wherein the pyrolizing is effected via at least one of a laser (24), an electron beam, an arc heat source and/or a plasma heat source.

**6.** The method as recited in claim 4 or 5, wherein the pyrolizing is effected with a meltsolidification process that forms a melt pool.

**7.** The method as recited in claim 4, 5 or 6, wherein:

the feedstock powder (36) is blown into the heat source; and/or
the feedstock powder (36) is in a powder bed process.

## Patentansprüche

**1.** Ausgangspulver (36) für einen additiven Fertigungsprozess, umfassend:

ein präkeramisches Polymer (40), das mit einem Basismaterial (42) vermischt ist, wobei das Basismaterial (42) Metall und ein Agglomerat mit dem präkeramischen Polymer (40) ist; und
ein Bindemittel, das mit dem Basismaterial (42) und dem präkeramischen Polymer (40) vermischt ist, wobei das Bindemittel Polyvinylalkohol ist,
wobei das präkeramische Polymer (40) zu Siliciumcarbid oder Siliciumnitrid pyrolysierbar ist und das Basismaterial (42) Nickel beinhaltet.

**2.** Ausgangspulver nach Anspruch 1, wobei das pyrolysierte präkeramische Polymer (40) ein volumetrisches Verhältnis von etwa 1 % bis 50 % bildet.

**3.** Ausgangspulver nach Anspruch 2, wobei das pyrolysierte präkeramische Polymer (40) ein volumetrisches Verhältnis von etwa 1 % bis 10 % bildet.

**4.** Verfahren der additiven Fertigung, umfassend: Schmelzen und Pyrolysieren eines Ausgangspulvers (36) nach Anspruch 1, 2 oder 3.

**5.** Verfahren nach Anspruch 4, wobei das Pyrolysieren mittels mindestens eines aus einem Laser (24), einem Elektronenstrahl, einer Lichtbogenwärmequelle und/oder einer Plasmawärmequelle ausgeführt wird.

**6.** Verfahren nach Anspruch 4 oder 5, wobei das Pyrolysieren mit einem Schmelz-Erstarrungsprozess ausgeführt wird, der ein Schmelzbad bildet.

**7.** Verfahren nach Anspruch 4, 5 oder 6, wobei:

das Ausgangspulver (36) in die Wärmequelle geblasen wird; und/oder
das Ausgangspulver (36) in einem Pulverbettprozess vorliegt.

## Revendications

**1.** Poudre de charge d'alimentation (36) pour un processus de fabrication additive, comprenant :

un polymère précéramique (40) mélangé avec un matériau de base (42), dans laquelle le matériau de base (42) est un métal et un aggloméré avec le polymère précéramique (40) ; et
un liant mélangé avec le matériau de base (42) et le polymère précéramique (40), dans laquelle

le liant est un alcool polyvinylique,
dans laquelle le polymère précéramique (40) est pyrolisable en carbure de silicium ou en nitrure de silicium et le matériau de base (42) comporte du nickel.

2. Charge d'alimentation selon la revendication 1, dans laquelle le polymère précéramique pyrolysé (40) forme un rapport volumétrique d'environ 1 % à 50 %.

3. Charge d'alimentation selon la revendication 2, dans laquelle le polymère précéramique pyrolysé (40) forme un rapport volumétrique d'environ 1 % à 10 %.

4. Procédé de fabrication additive, comprenant : la fusion et la pyrolyse d'une poudre de charge d'alimentation (36) selon la revendication 1, 2 ou 3.

5. Procédé selon la revendication 4, dans lequel la pyrolyse est effectuée via au moins l'un d'un laser (24), d'un faisceau d'électrons, d'une source de chaleur à arc et/ou d'une source de chaleur à plasma.

6. Procédé selon la revendication 4 ou 5, dans lequel la pyrolyse est effectuée avec un processus de solidification à l'état fondu qui forme un bain de fusion.

7. Procédé selon la revendication 4, 5 ou 6, dans lequel :

la poudre de charge d'alimentation (36) est soufflée dans la source de chaleur ; et/ou
la poudre de charge d'alimentation (36) est dans un processus de lit de poudre.

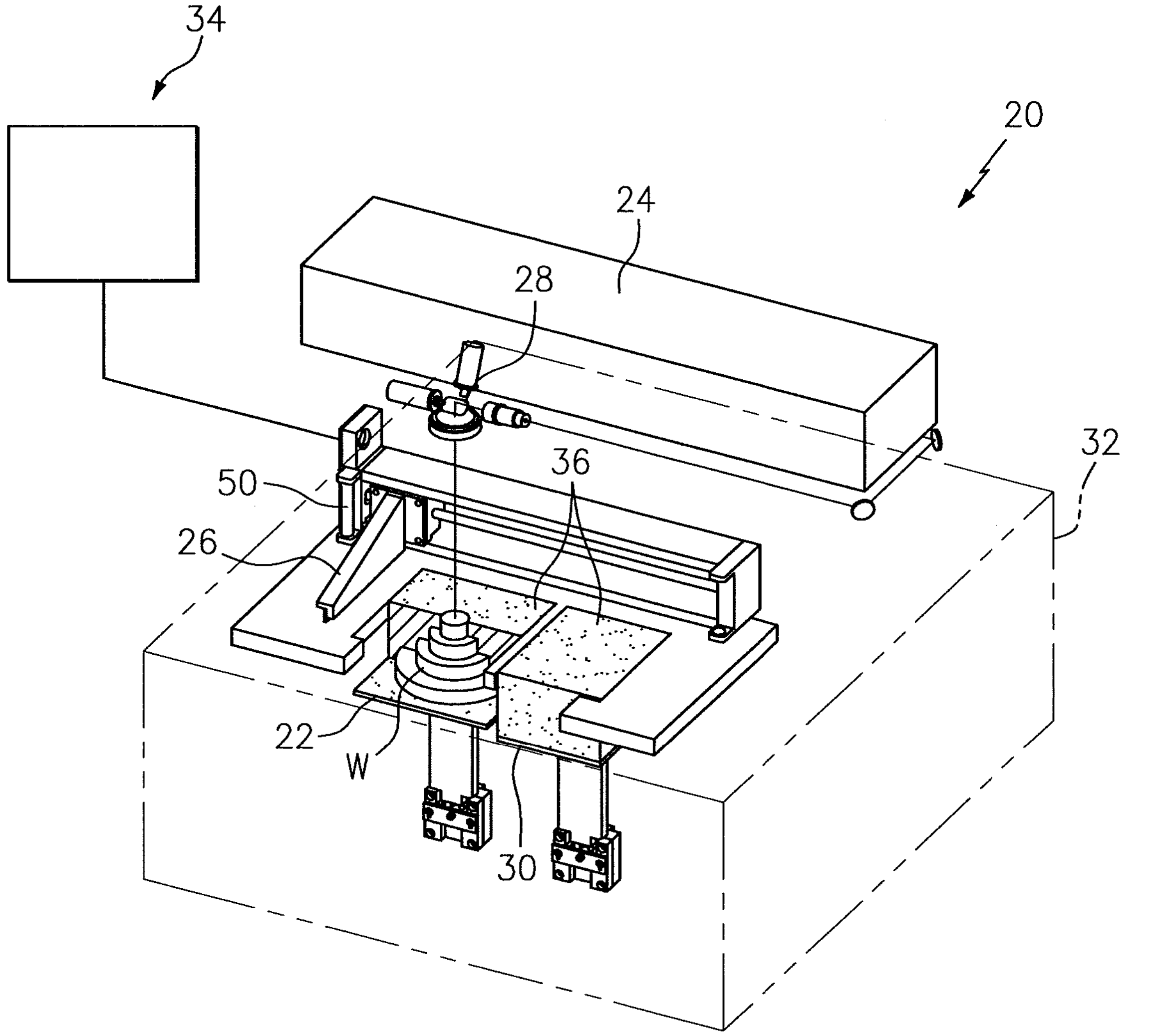


*FIG. 1*

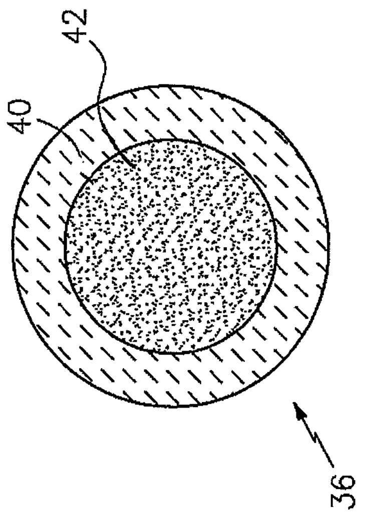


FIG. 2

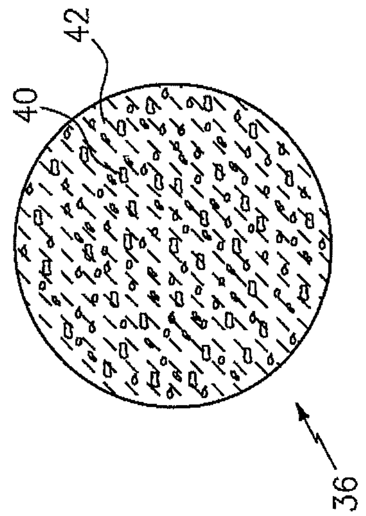


FIG. 3

## REFERENCES CITED IN THE DESCRIPTION

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